Socio-economic Vulnerability to Localized Severe and Tornadic Events with a Focus on Communities in Alabama

An Honors Thesis (HONR 499)

by

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Abstract

As evidenced by our 24-hour news cycle, as well as the proliferation of reality television, the depiction of severe weather, particularly the devastation caused by tornadoes, and its effects on local communities has been of increasing popularity over the past decade. This coverage, in many instances, has acted as a catalyst for individuals to reflect on whether or not certain areas, or communities, are prepared for such events to occur. Communities themselves inherently exhibit particular social and economic characteristics such as age, population, density, poverty, and housing condition based on the individuals or infrastructure that resides within. The degree to which these socioeconomic conditions are present may impact that community's ability to be physically and financially resilient to the occurrence of severe weather. Understanding how severe weather events affect society and how communities are able to prepare for, respond to, and recover from such an event is an important factor in developing equipped and knowledgeable citizens. This paper proposes and analyzes various socio-economic factors that could increase a community's vulnerability to severe weather and where, geographically, they are most prevalent. Through the creation of a socio-economic vulnerability index, this paper analyzes what communities appear to be at an increased level of risk during a severe weather event and how these communities were impacted during one of the most historic tornado outbreaks across the state of Alabama.

Acknowledgments

I would like to thank Dr. Reuben Allen for the time and effort he put forth to help me accomplish the construction of the vulnerability index and ultimately the paper itself. I would also like to thank all of my friends here at the University for continually encouraging me and providing me with helpful information to complete the project.

Authors Statement

The purpose of this research paper was to analyze socio-economic vulnerability to severe weather within local communities. Our focus was on tornadic events and how the combination of certain social and economic demographics can affect the level of risk within certain populations. Our defined 'community ' was that of a United States Census tract, given their overall homogeneity with respect to the demographic composition of its occupants. Our area of study was the state of Alabama so as to compare predicted vulnerability to the tornado outbreak of April 27, 2011, which was one of the deadliest on record and devastated much of the state. Our socio-economic vulnerability index was created based on a composite Z-score calculation, taking into account multiple different variables obtained from the United States Census Bureau's American Community Survey 5-Year Estimate datasets. This composite score was arbitrarily classified into 6 classes and choroplethed, or colored, with a diverging color scheme of green to red (green being less vulnerable and red being highly vulnerable). Other data including the tornado tracks, roads, total deaths, total injuries, and monetary damage were also mapped at various scales. Our ultimate goal was to assess if any type of correlation existed between those tornado tracks that produced high numbers of fatalities and injuries and the impacted census tracts that were classified as highly vulnerable. We also wanted to determine what demographic factors contributed the most to increased vulnerability in the affected tracts. Through the work done in connection with this study, we hope to better understand what factors affect a population's vulnerability to severe weather and by doing so, unveil possible social factors that could be addressed or changed in order to develop more resilient and protected citizens.

Socio-economic Vulnerability to Localized Severe and Tornadic Events with a Focus on Communities in Alabama

An analysis and comparison study of the tornado outbreak that took place on April 27, 2011 across the state of Alabama

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Synopsis

In today's media driven world, we are often inundated with news feeds and articles discussing the severity and increasing regularity with which local towns and communities are devastated by the occurrences of strong, severe, and often deadly tornado outbreaks. With some of the deadliest and costliest tornado outbreaks having occurred within the past two decades, combined with the evolution of particular demographic, social, and economic factors, it can be seen why current efforts to understand, analyze, and alleviate socio-economic vulnerabilities within susceptible communities is imperative to generating knowledgeable citizens and ultimately resilient and prepared towns and cities. The purpose of this paper and subsequent analysis is to shed light on factors that increase the vulnerability of a community to severe weather, particularly tornadic events, through the creation of a socio-economic vulnerability index and an analysis with the historic outbreak of April 25-28 in the southern United States. The particular focus of this paper will be the portion of the outbreak that occurred on April 27 in the state of Alabama.

Conceptualizing Vulnerability and Location

Vulnerability can take on multiple different meanings depending upon what context and setting the term is used. The concept changes especially when analyzing it with respect to severe weather and environmental hazards. At its essence, vulnerability to environmental hazards is the potential for loss, and this potential is dynamic in that it varies over geographic space and time (Cutter et al., 2003). Many of the impacts associated with severe weather events and natural hazards such as tornadoes are disproportionately based on the social, physical, and economic composition of the local communities and neighborhoods affected by such events. Many of these communities lack the basic infrastructure and economic opportunity to withstand environmental disasters, thus making the public health and economic consequences more severe (Cutter et al., 2003).

Assessing Risk

When a multitude of different factors combine, such as, a community's vulnerability (socio-economic vulnerability for this study), people's access to resources (or lack thereof), and as the presence or likelihood of experiencing a natural hazard, it provides an indication of an area's overall *risk*. The idea of *risk* is often conceptualized by the equation:

*Risk = Hazard * (Vulnerability – Resources)*

where *risk* is the overall expectation of loss, *hazard* is the condition posing a threat or harm, and *resources* are those assets in place that will help diminish the effects of said hazard (Flanagan et al., 2011). Therefore, when an area is prone to natural hazards, has limited access to resources, and is socially and economically vulnerable, they are at a greater *risk* of experiencing events that could lead to immense devastation and possibly even death. It can be surmised that each of these inputs (hazard, vulnerability, and resources) may not play an equal role in the development of risk and will be dynamic from community to community. Also, as mentioned, each of these inputs will vary over space and time.

Establishing the Hazard

Areas all across the United States have the potential to be affected by the impacts of a tornadic event, however, these occurrences are particularly great in one of the regions know as "Tornado Alley". According to Concannon et al. (2000), the primary area in the U.S. in which significant tornadoes occur most often is in an L-shaped region from Iowa to Oklahoma to Mississippi. A lesser known, but important geographic location for this study, is the region now often termed as "Dixie Alley". This region's geographic extent is often a debated topic, but at its essence, it encompasses portions of the southeastern United States including that of Arkansas, Louisiana, Mississippi, Tennessee, Alabama, and Georgia (Gagan et al., 2010). This particular region is important to note given that recent studies have indicated differences in vulnerability parameters between the traditional "Plains Tornado Alley" (e.g. Nebraska, Kansas, Oklahoma) and "Dixie Alley", with higher vulnerabilities and dangers being present in the "Dixie Alley" region. According to Gagan et al. (2010), Dixie Tornado Alley (DTA) has reported a higher incidence of fatalities, injuries, and killer tornadoes as compared to the Plains Tornado Alley (PTA) from 1950-2007 (Table 1). Additionally, the DTA seems to be at a greater risk of experiencing strong tornadoes during the overnight hours, a factor that greatly increases vulnerability and susceptibility. It can be seen that these statistics for the DTA, when combined with socio-economic factors that can increase a community's vulnerability, indicate the dangers of having unprepared and susceptible citizens living in regions that are often exposed to hazardous and sometimes deadly severe weather events. Given that north-central Alabama is examined in this study and is located in the DTA, an understanding of this area's risk to severe and deadly tornadic events is important.

Table 1: Comparison of the DTA and PTA with respect to fatalities, injuries, killer tornadoes, and the frequency of killer tornadoes with respect to local time. Data obtained from Gagan et al. valid for the time period 1950-2007.

	Dixie Tornado Alley	Plains Tornado Alley
Fatalities	1705	991
Normalized by Pop.	6.8/100,000	5.6/100,000
Injuries	26,026	14,709
Normalized by Pop.	104/100,000	83/100,000
Number of Killer Tornadoes	371	205
Percentage of Killer Tornadoes (9PM-7AM LT)	34.0%	21.0%

Natural Hazard Evolution

The weather is in constant flux and the overall patterns of the atmosphere change from time to time, bringing with it changes to the environment such as the occurrences of droughts, extreme flooding, and severe weather to name a few. However, the number and severity of extreme and severe weather and climate events in the United States has risen since 1980, and is projected to continue to rise throughout this century (NOAA, 2013). This is due to a combination of climate variability and an influx of people into highly vulnerable regions that are prone to severe and extreme weather, particularly urban and coastal environments. If these observed trends continue, it is speculated that economic damages from extreme weather events could grow four times greater by 2050 (ibid). This discussion further provides evidence for the importance of accurately understanding what factors influence, and ultimately increase, local communities' vulnerability in order to assess such issues to develop educated, prepared, and resilient citizens.

Analyzing Resources

The resources that are available to citizens of a particular community are those assets that help diminish the effects of a particular hazard. These resources could function as either prevention measures that would aid in informing and protecting individuals before an event occurred, or recovery measures that would aid in medical treatment and the stabilization and revitalization of a community after an event. Resources that serve as prevention measures are often referred to as mitigation efforts, or strategies. If these resources are effective, they should ultimately help reduce a community's vulnerability by helping to put in place various measures that develop resiliency to a natural hazard impact (Dwyer et al., 2004). These could include, but are not limited to, measures such as reputable severe weather warning dissemination and citizen access (via phone, internet, television, radio, or siren), ensuring infrastructure is well maintained and constructed to specifications, having severe weather plans and shelters in place (both in the private and public sector), and the development of education programs to expand citizen awareness and knowledge. Post-event resources would be those assets that specifically help with the recovery process. In a general context, recovery is the ability for a community and its citizens to re-attain a lifestyle state that is comparable to the one they had prior to the hazard impact (ibid). This could include access to medical facilities for further treatment of the injured, individual access to and possession of insurance, the development of social support networks for those affected, as well as community access to local, state, and national governmental response and aid to name a few. It is important to understand what preventative measures are present or lacking from particular areas in order to better understand the measures or changes that need to be enacted in order to develop more resilient and less vulnerable communities.

Theoretical Framework

Factors Affecting Socio-economic Vulnerability

Multiple factors influence the vulnerability of the population within a community, some of which are agreed upon while others are still up for debate. Understanding just how each of these factors influences a community and its ability to prepare for and recover from a natural hazard is also a topic of debate. Through the study of these factors in this analysis, we hope to provide a better understanding of how these factors incorporate into the vulnerability paradigm of local communities, particularly with respect to tornadic events. Some of the major factors that were analyzed and incorporated included: type and density of infrastructure and the built environment; social and age make-up of the home environment (single parent, presence of young children, presence of elderly); dependence of householder/occupant; occupation and average income; education and availability/access to resources (technological); building stock and age; and foreign and/or minority populations. As mentioned earlier, each of these factors is dynamic in the realm of local communities given that the social, physical, and economic structure of populations is ever changing and evolving over both space and time. For this particular study, data associated with a 5-year average for Alabama census tracts from the American Community Survey were used in order to account for this dynamism and provide the study with the average socio-economic conditions in the years prior to and including the tornado outbreak in 2011.

Table 2: Factors, and their primary components, that often influence (increase) the socio-economic vulnerability of a community. These were used as a guide during the selection of variables for the creation of our vulnerability index.

Factor	Primary Component(s) Increasing Vulnerability
Economic Status (income, poverty, occupation)	Low income; high poverty; occupations in primary activities (forestry, fishing, mining, etc.); unemployed
Household Composition	Single parent (either male or female as primary guardian); grandparents as primary guardian
Age	Elderly (defined as 65 years or older); young (dependents, defined as under 18 years)
Gender	Female (particularly those that have recently had birth or have newborns)
Race/Ethnicity	Non-white; minority populations
Language	Non-English (often related to race/ethnicity factor)
Education	Lack of (no high school diploma or less)
Resources (technological)	No access to telephone service or vehicle
Density of Population	High Density (large population per land area)

Density of Urban Landscape	High Density (large number of houses/units per land area)
Property Type	Multi-family homes; multi-unit structures (duplexes, apartments); mobile homes
Housing Age	Houses built prior to 1990 (20+ years old at time of event)
Geographical Familiarity	Recently moved (within last year; could be foreign or domestic population)

Detailing the Factors of Vulnerability

Economic Status

Household income, poverty, and the sector of employment held by local citizens are all factors that can and do affect how resilient communities are to severe local storms. The economic status of a community and its members provides an indication as to how well they are able to absorb and recover from the effects of a natural hazard such as a tornado outbreak. Communities and families that are predominantly low-income are at an increased risk to environmental hazards due to different underlying factors such as a lack of access to economic opportunities, prevalence of poor infrastructure and housing, possible exposure to hazardous materials, and a general lack of access to resources such as food, shelter, and technology (Ross, 2013). Low-income families, or those that fall within poverty status, often lack access to technological resources such as mobile phones, television, or the Internet, which can provide life-saving severe weather warnings. Severe weather can also disrupt local economies and job sectors by preventing citizens from getting to work or by destroying businesses and operations that supply local jobs. This is especially of interest in low-income communities, whose workers largely depend on each paycheck and have little savings to fall back on (ibid). Jobs related to the primary sector of employment (forestry, fishing, mining) are often at an increased susceptibility as well given that particular natural hazards, especially tornadoes, can lead to the total destruction of the resources that these jobs are depend on.

Household Composition/Age/Gender

Individuals who are young (defined as dependents under the age of 18) or elderly (defined as being over the age of 65) could be at increased risk to severe weather events due often to their dependence on others for care, a decreased capacity in mobility and cognition, as well a general lack of resources or knowledge (particularly for the young). If these individuals lack the necessary resources in order to be cared for or taken to a sheltered area, they could be at a greater risk of suffering from injury or death during a severe weather event. From the years 2000-2010, the total number of households in the United States increased by 10.7 percent, with only 48.4 percent of all 2010 households being considered "traditional", in which both a husband and a wife were present (Lofquist et at., 2012). This value was down approximately 4 percent from 2000 and 7 percent from 1990.

Moreover, more women than men lived alone and those having a female as the head of the house dominated most single parent homes. Single parent homes often increase the risk to hazards given that the role of caring and protecting now lies in the hands of one individual instead of two, increasing the likelihood of inadequate or insufficient attention and care. Single-family homes are often associated with overall lower income and higher poverty given the presence of only one source of monetary funds. This in turn negatively affects the number and quality of resources available to these families and their members. A recent study has also shown that women disproportionally suffer the impacts of disasters and severe weather events because of cultural norms and the inequitable distribution of roles, resources (including income), and power (Yavinsky, 2012).

Race/Ethnicity/Language

Race, ethnicity, and the predominant language spoken in a household can increase that household's vulnerability, especially if its members are those of a minority group or speak a language other than English. These factors increase vulnerability through a general lack of access to resources, cultural differences, and social, political, and economic marginalization often associated with minority ethnic, racial, and language groups (Cutter et al., 2003). Many of these individuals are not proficient in the English language, both spoken and written, making disaster communication increasingly difficult and thus limiting the degree to which groups of individuals can receive, disseminate, and appropriately act upon severe weather warnings and information.

Education/Resources/Geographical Familiarity

The presence and proliferation of poverty in a community is often linked to factors such as a lack of access to health, education, and other services and resources (Philip and Rayhan, 2004). Those individuals that lack sufficient education (less than a high school diploma) are often associated with lower paying jobs and an overall reduction in access to resources as compared to higher-income families or households. They may also be less familiar with how to acquire information during severe weather events, how to interpret these warnings if accessible, or how to appropriately react to this information. Resources such as availability to motor vehicle access, telephone services, and Internet access often serve as vital sources of information retrieval and means of contact during severe weather events. Communities that are categorized as lower-income and/or higher poverty are often lacking these resources due to an inability to afford or access such forms of capital (ibid).

Another concept that could be placed with education is this idea of geographical familiarity. This is the idea that groups of people become accommodated to or familiar with certain cultural, social, or physical aspects typical of a certain area after a period of time during which phenomena are experienced. (Huebel et al., 2013) In this case, phenomena would be the occurrence of tornadic events in the southern United States. Individuals who have lived in an affected area for an extended period of time are often more prepared for and aware of severe weather situations when they occur. If a person or group of people have recently moved or immigrated to a commonly affected area, but are not accustomed to such an event, they are likely going to be at an increased vulnerability to injury or death, given their lack of understanding, knowledge, and preparedness.

Population and Urban Landscape Density

Many individuals are driven towards urban environments as jobs in the tertiary and quaternary sectors of the economy continue to grow and dominate. From 2000-2010, the nation's urban population increased by 12.1 percent and accounted for 80.7 percent of the total population at the end of this time period (Census, 2012). According to the Census Bureau, urban areas are defined as densely developed residential, commercial, and other nonresidential areas. Communities located within or near urban centers are often designed in such a way to maximize the housing and structural occupancy over a given land area. This results in regions of high-density residential and commercial buildup as well as high-density population clusters. A large number of individuals located within a small geographic area limits the ease of movement and increases the risk of having a significant number of people in danger if a disaster-type event were to affect an urban environment. The concentration of population in urban areas, combined with urban sprawl, has increased the threat of large fatality figures if a large, violent, long-track tornado were to hit a major metropolitan area (Brooks et al., 2008).

Property Type and Age

The vulnerability of a community and its members is also affected by the quality, age, and type of housing they are able to occupy. This idea is often tied to the predominant age of the housing in a community but also to other economic factors such as income. One of the primary reasons that low-income people are disproportionately affected by extreme weather is due to the quality of their housing. Substandard construction and the age of affordable housing—generally in less-than-desirable neighborhoods that lack quality services and are supported by subpar infrastructure—puts low-income people at greater risk from the effects of severe weather (Ross, 2013). Also the size and type of housing can affect vulnerability to severe weather. Multiunit structures such as apartments increase the density of the built environment and often offer less protection as compared to a traditional single-family home given their multi-storied floors and limited shelter areas. Mobile homes serve as another dangerous housing structure to the safety of those inside. Mobile homes are especially vulnerable targets during tornadic events given their propensity to be rolled over during gusty winds (as minor as 60-70 mph) with the higher winds of a tornado possibly leading to the disintegration of the entire structure (Stanford, 1987).

Methods and Approach

Socio-economic Vulnerability Index

For this study, social, economic, and other demographic information was selected from the United States Department of Census' American Community Survey (ACS) datasets, specifically from their five-year average estimates. This data was aggregated at the census tract level for the state of Alabama. The ACS 5-year estimate dataset from which data was selected and analyzed was valid for the years 2007-2011. This dataset was targeted given that it represents the population of the state of Alabama for the 4 years prior to as well as the year of the outbreak. This provided our analysis with a good estimate as to the average socio-economic conditions of the census tracts in the study area during the tornadic event, which occurred in April of 2011. If needed, the data was normalized based on area or population, in order to standardize the data set.

Table 3: A list of the names of the variables incorporated into the creation of the socio-economic vulnerability index.

Variable Names
Total Pop. Per sq. km
Total Households per sq. km
Family Households per sq. km
Family households with children under 18 yrs. per sq. km
Family Households, no wife present per sq. km
Family households, no wife present, with children under 18 yrs. per sq. km
Family Households, no husband present per sq. km
Family Households, no husband present, children under 18 per sq. km
Nonfamily Household, Householder living alone per sq. km
Nonfamily household, householder living alone, over 65 per sq. km
Households with one or more under 18 yrs. per sq. km
Households with one or more 65 and over per sq. km
Average household size
Average family size
Number of women 15-50 who gave birth in past 12 months per sq. km
Grandparents living with grandchildren under 18 yrs. per sq. km
Grandparents responsible for grandchildren under 18 yrs. per sq. km
Population 3 yrs. and over enrolled in school per sq. km
Number of individuals with less than 9th grade education per sq. km
Number of individuals with 9th-12th grade education, no diploma per sq. km
Population living in a different house 1 yr. ago per sq. km
Population living in a different state 1 yr. ago per sq. km
Population abroad 1 yr. ago per sq. km
Foreign born population per sq. km
Population not a us citizen per sq. km
Population that speaks language other than English per sq. km
Population that speaks English less than very well per sq. km
Unemployed pop per sq. km
Population in primary activities per sq. km
Population with income less than $50,000 per sq. km
Mean household income (dollars)
Mean family income (dollars)
Per capita income (dollars)
Population below poverty level per sq. km
Total housing units per sq. km
Number of structures with 5 or more units per sq. km
Number of mobile homes per sq. km
Number of structures built before 1990 per sq. km

Number of housing units with no vehicle available per sq. km
Households with no telephone service per sq. km
Housing units with 1.51 or more occupants per room per sq. km

Once all of the data were compiled, a factor analysis, specifically a principal components analysis, was performed in order to determine correlation among the selected variables and to incorporate these correlated variables into clusters, or components. These clusters, and their associated variables, were then used to assign a statistical standard score to each of the census tracts in Alabama. The standard scores for all five factors were added together and averaged for each census tract in order to generate a composite score, or the score representing our Socio-economic Vulnerability Index. Our initial dataset was comprised of 41 independent variables, which were consolidated into 5 clusters, or components, upon the completion of the factor analysis. These 5 components accounted for slightly more than 79 percent of the variance.

Table 4: A list of the 5 components or clusters generated from the principal components analysis including the factor name, the percent of variation explained by each, the dominant variable, and the correlation of each variable.

Variation of Components

Component	Name	Percent Variation Explained	Dominant Variable	Correlation
1	Population Density	50.94	Family households per sq. km	+ 0.945
2	Wealth	11.57	Population with income less than $50,000 per sq. km	+ 0.907
3	Immigrant & Recently Moved	7.74	Foreign born population per sq. km	+ 0.970
4	Lack of Education & Access to Resources	5.47	Number of individuals with at most a 9th-12th grade education level but no diploma per sq. km	- 0.380
5	Elderly Population & Infrastructure	3.72	Number of householders over 65 living alone per sq. km	-0.418

Results and Analysis

The Socio-economic Vulnerability Index created ranges from -1.41 (low socio-economic vulnerability) up to 5.59 (high socio-economic vulnerability) with a mean vulnerability score of around 0 for all Alabama census tracts. These values representing vulnerability were mapped and displayed in two different formats, one showing the raw vulnerability composite scores divided into 6 classes (Figure 1) and another dividing the dataset into 3 classes via a quantiles break classification method (Figure 2). For the latter classification, the range representing the lowest vulnerability scores was labeled as 'Least Vulnerable', the middle tier as 'Moderately Vulnerable', and the highest tier of scores labeled as 'Most Vulnerable'. Each category is comprised of 379 census tracts (excluding tracts with no data).

Of the census tracts with the highest socio-economic vulnerability, 4 out of the top 5 are located within the urban environment of Birmingham, Alabama. Within the top 20 most vulnerable census tracts, many are located within or near urban settings such as the cities of Birmingham, Huntsville, Tuscaloosa, Montgomery, and Mobile. (See figures 3, 4, 5, 6, and 7) The largest components contributing to these tracts' higher vulnerability are across the board; high densities of population and housing, high proportions of the population being of either foreign descent or having recently moved to the area, or high poverty and/or low income. Of the least vulnerable census tracts, vast majorities are located in the rather rural areas of southwest central Alabama with many of these tracts being adjacent to one another. These tracts in particular tended to be areas characterized by much lower population and housing densities.

Urban and Rural Landscapes

If we consider analyzing the socio-economic vulnerability of the urban versus rural landscapes, we begin to see distinct patterns that develop within these communities. For this discussion we have defined urban according to the definition supplied by the Census and the United States Department of Health and Human Services as "territory, population, and housing units located within an urbanized area or and urban cluster which has a population density of at least 1,000 people per square mile, or 386 people per square kilometer" (Health Resources and Services Administration). The census tracts were divided up using this criterion, which resulted in 720 tracts classified as rural and 417 tracts classified as urban (excluding those tracts associated with no data).

Socio-economic Vulnerability Composite Score Index
(Alabama Census Tracts, 2007-2011)

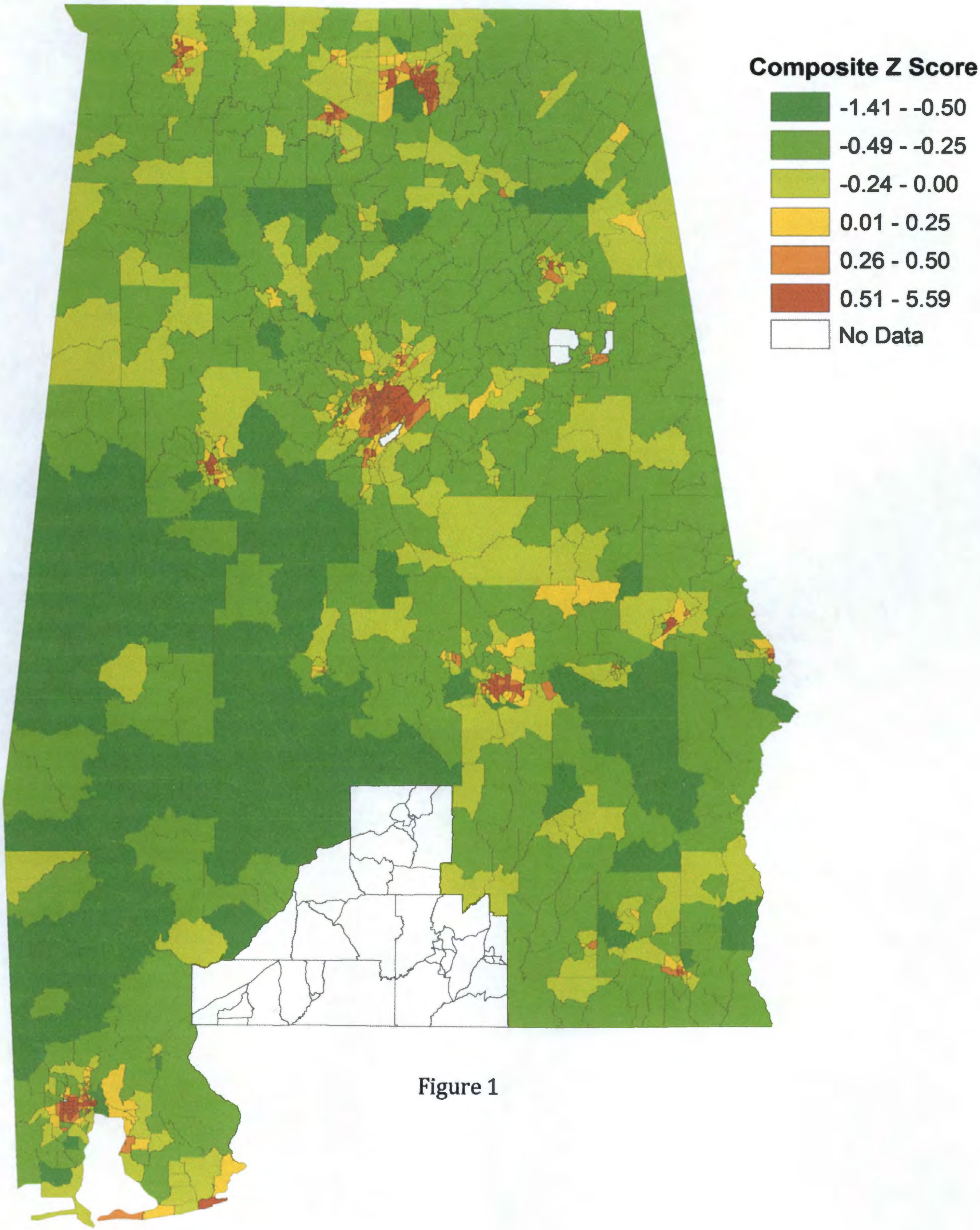

Figure 1

Socio-economic Vulnerability by Category
(Alabama Census Tracts, 2007-2011)

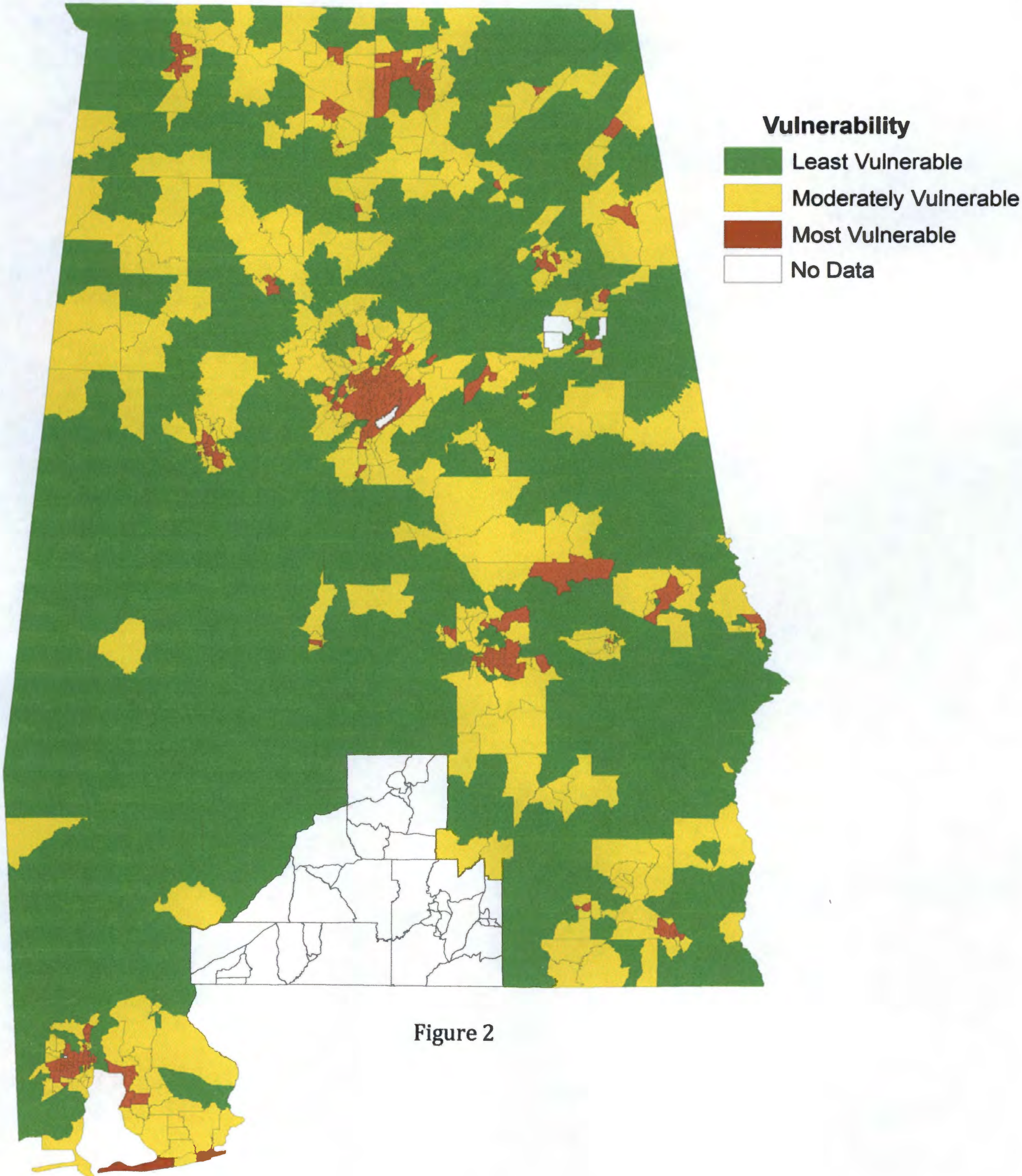

Figure 2

According to the data, those census tracts classified as urban had, overall, a higher average vulnerability score at 0.51 as compared to the average vulnerability score of the rural tracts, which came in at -0.29. The factors, or components, that contributed

Birmingham, AL Vulnerability Map

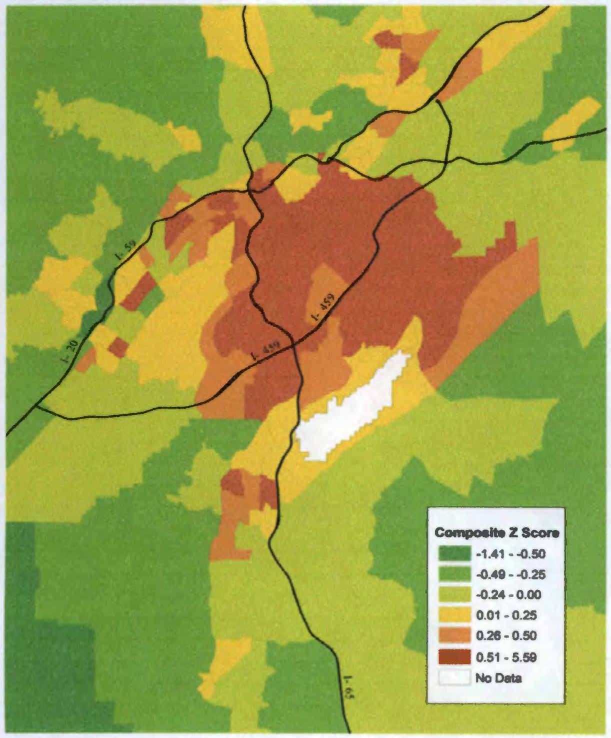

Figure 3

Montgomery, AL Vulnerability Map

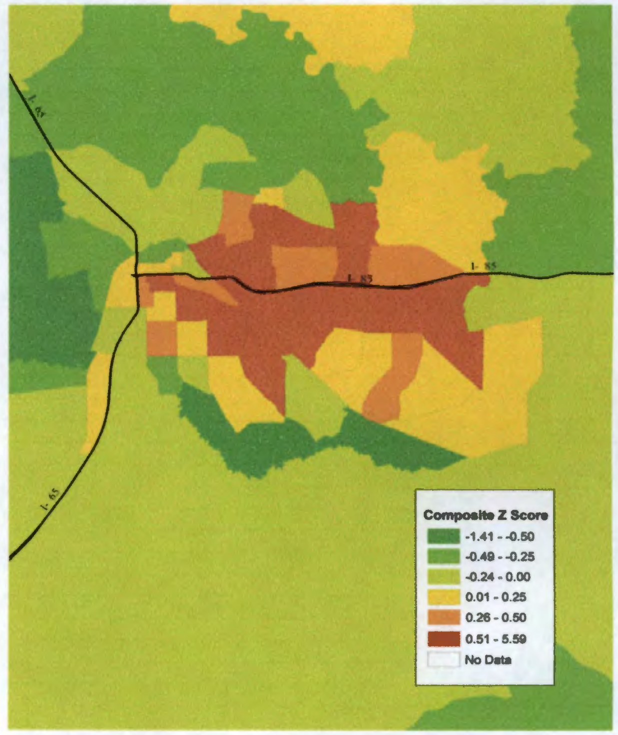

Figure 4

Tuscaloosa, AL Vulnerability Map

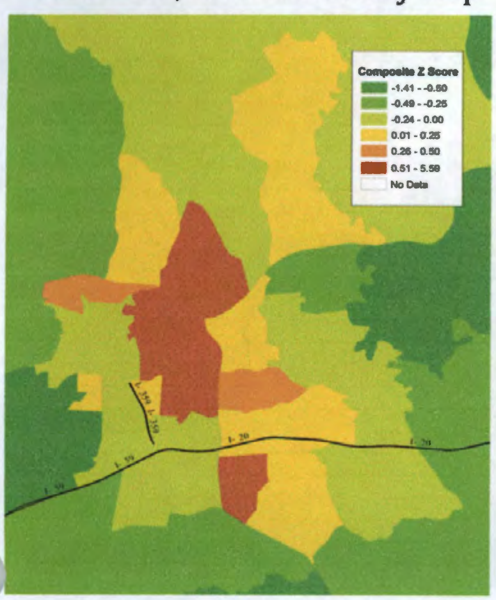

Figure 5

Huntsville, AL Vulnerability Map

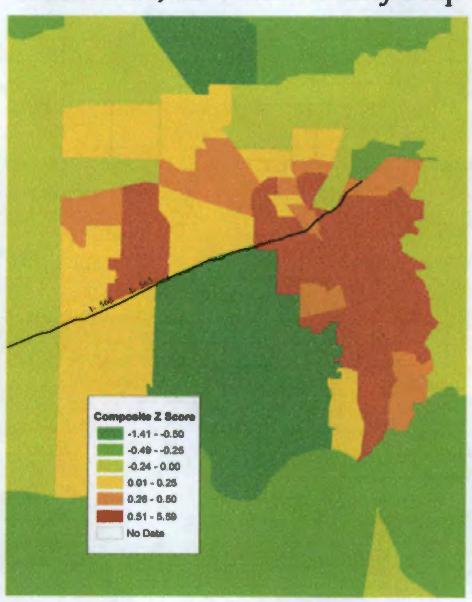

Figure 6

Mobile, AL Vulnerability Map

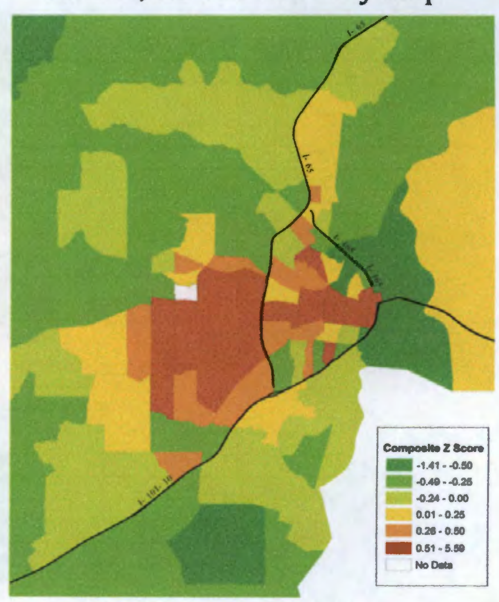

Figure 7

the most to this average vulnerability score for the urban tracts were population and housing density, wealth, and immigrant/recently moved population. The components that contributed the least to this score were older communities and large proportions of elderly individuals as well as a lack of education and access to resources. Urban areas tend to be dominated by high population and housing densities as well as high proportions of individuals who are either of a foreign descent or have recently moved to the area (from either foreign or domestic locations). They also often have clusters or communities dominated by low income populations. Each of these components adversely affects a community's ability to prepare for and recover from natural disasters such as tornadoes, and thus would be characterized by greater vulnerability.

The tracts classified as rural displayed the exact opposite in terms of the component contribution to the average vulnerability score. Those factors that contributed the most to rural tracts' vulnerability were an overall lack of education and access to resources as well as a predominance of elderly individuals within the tract. Low population and housing densities, increased wealth and lower poverty levels, as well as low proportions of foreign or recently moved populations were the major components contributing to lower vulnerability scores within the rural tracts. With respect to population density, across the 720 tracts classified as rural for Alabama, the average population density is 25.82 people per square kilometer as compared to the 417 tracts classified as urban, which have an average population density of 755.50 people per square kilometer.

Table 5: The average vulnerably scores for each of the 5 components for the urban and rural census tracts respectively.

	Population Density	Wealth	Immigrant/Recently Moved	Lack of Education/Access	Elderly Pop./Infrastructure
Urban	1.019	0.718	0.446	0.061	0.289
Rural	-0.590	-0.416	-0.258	-0.035	-0.167

Vulnerability and Tornado Outbreaks: April 27, 2011 Alabama Outbreak

Event Overview

During the day of April 27, 2011 a series of devastating and dangerous tornadoes ravaged much of the southeastern United States, in particular the state of Alabama. There were multiple distinct waves of storms that made their way across the state during the course of the day. The first round occurred during the early morning hours, another around midday, and the final, which produced the strongest and most destructive tornadoes, occurred later that afternoon and evening. At the end of the day, 62 tornadoes were confirmed across the state (NWS Birmingham, AL). Within Alabama alone, the tornadoes affected 35 counties, resulting in 247 fatalities across 19 counties (Figure 8), over 2000 injuries (Figure 9), and over $4 billion in damages (Figure 10) (Chiu et al. 2013). This outbreak was one of the deadliest in the country since tornado record keeping began in the 1950's and ranks in severity with the 1974 Super Outbreak that impacted the Midwest and Southern United States (Hayes, 2011).

Table 6: Deaths, injuries, and monetary damage by Alabama county associated with the tornadoes of April 27, 2011. Data obtained from NOAA's Storm Events Database

Counties	Direct Deaths	Direct Injuries	Property Damage ($)
Autauga	0	0	0
Baldwin	0	0	0
Barbour	0	0	0
Bibb	1	10	14,284,000
Blount	0	13	24,364,500
Bullock	0	0	0
Butler	0	0	0
Calhoun	9	26	126,000,000
Chambers	0	0	2,015,000
Cherokee	0	25	19,000,000
Chilton	0	1	102,000
Choctaw	0	0	8,600,000
Clarke	0	0	0
Clay	0	0	0
Cleburne	0	0	0
Coffee	0	0	0
Colbert	0	0	0
Conecuh	0	0	0
Coosa	0	0	0
Covington	0	0	0
Crenshaw	0	0	0
Cullman	2	0	20,000,000
Dale	0	0	0
Dallas	0	0	0
DeKalb	31	0	30,000
Elmore	6	20	50,000,000
Escambia	0	0	0

Etowah	0	0	9,400,000
Fayette	4	4	11,081,000
Franklin	27	0	50,600,000
Geneva	0	0	0
Greene	0	0	7,500,000
Hale	6	40	17,350,000
Henry	0	0	0
Houston	0	0	0
Jackson	8	0	0
Jefferson	20	720	723,500,000
Lamar	0	0	0
Lauderdale	0	1	0
Lawrence	14	0	40,000,000
Lee	0	0	0
Limestone	4	45	1,000,000,000
Lowndes	0	0	0
Macon	0	0	0
Madison	9	0	0
Marengo	0	3	14,000,000
Marion	25	200	176,700,000
Marshall	5	48	50,000
Mobile	0	0	0
Monroe	0	0	0
Montgomery	0	0	0
Morgan	0	0	400,000
Perry	0	0	1,945,000
Pickens	0	4	10,111,000
Pike	0	0	0
Randolph	0	0	0
Russell	0	0	0
St. Clair	13	35	200,865,000
Shelby	0	0	3,755,000
Sumter	0	2	1,268,000
Talladega	0	0	1,000,000
Tallapoosa	1	10	115,000,000
Tuscaloosa	44	800	1,514,430,000
Walker	9	60	128,400,000
Washington	0	0	0
Wilcox	0	0	0
Winston	0	25	115,00,000
Total	**238***	**2,092**	**4,303,250,500**

*9 deaths are unaccounted for in the county count

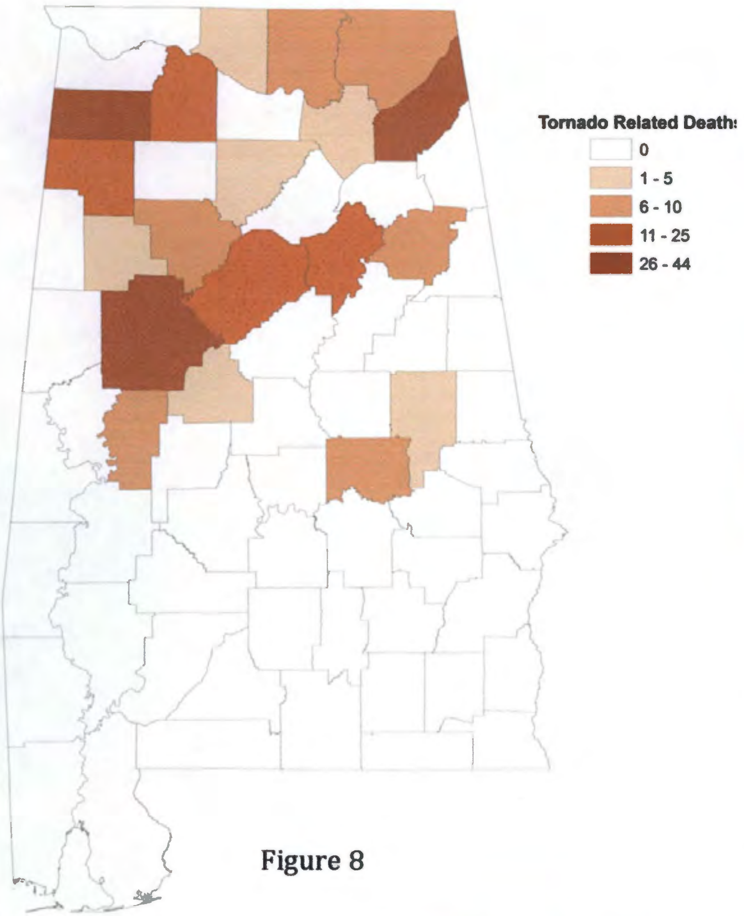

Figure 8

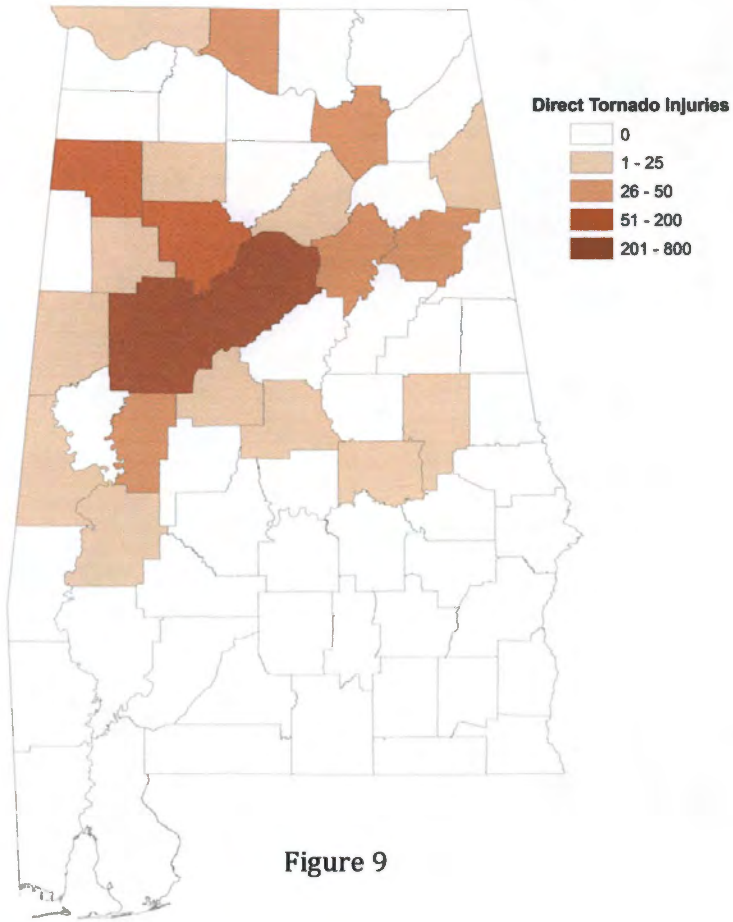

Figure 9

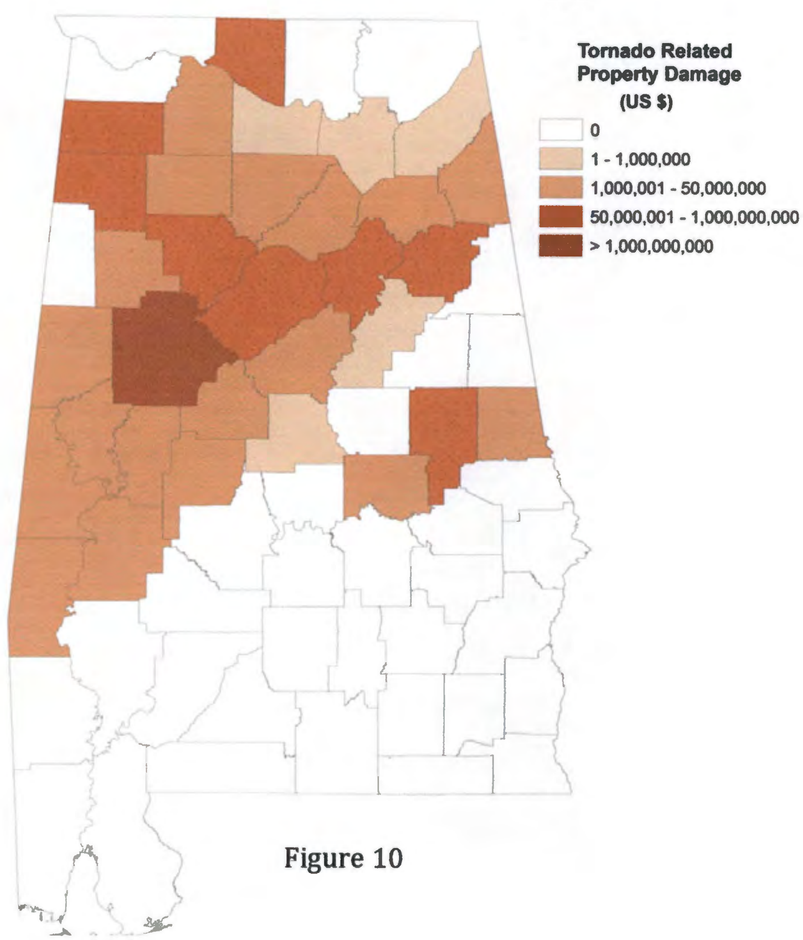

Figure 10

Table 7: Tornado counts by EF rating as well as the number of direct deaths, injuries and monetary damage associated with each EF-scale intensity. Data obtained from NOAA's Storm Events Database

EF-Scale Rating	EF-0	EF-1	EF-2	EF-3	EF-4	EF-5
Tornado Count	6	29	9	7	8	3
Related Deaths	0	2	1	24	127	84
Related Injuries	1	10	33	250	1,698	100
Related Monetary Damage (millions)	0.197	34.17	51.66	195.23	3,772.00	250.00

Fatality, Injury, and Monetary Damage Distribution by Intensity

Of the 62 tornadoes (tracks in Figure 11), only 11 were rated at producing EF-4 or EF-5 intensity damage (17.7%) with the remaining 51 at either EF-3 intensity or lower (82.3%). However, when analyzing the breakdown of fatalities, injuries and monetary damage, a clear distinction between these two groupings is noticeable (Table 7). Despite the fact that only 17.7% of the tornadoes were rated at an EF-4 intensity or above, these tornadoes were responsible for 211 (88.7%) of the reported fatalities, 1,798 (86.0%) of the reported injuries, and $4.022 billion (93.5%) in reported monetary damage.

Distribution of Fatalities by Demographics: A Snapshot of Vulnerability

Post event data was compiled from and by the American Red Cross as well the Center for Disease Control with respect to where and under what conditions the 247 tornado-related fatalities occurred during the outbreak. Based on the argument that women are at an elevated level of vulnerability, this study showed that females were at an increased risk of suffering a tornado-related death as compared to men. Of those deceased, 59.1% were observed to be female and the remaining 40.9% were male. With respect to age, 45.8% of the deceased were either under the age of 18 or over the age of 65. The highest risk of any age group was attributed to those individuals 85 years and older (Chiu et al., 2013). The study found that 82.6% of the deceased were White and 16.6% were Black. With respect to ethnicity, 98.8% were classified as Non-Hispanic. Of the deceased with known educational backgrounds, 81.0% were either still in school and under the age of 18 or only had a 12th grade level of education or less. Of the deceased with known occupations, 40.7% were classified as white collar, 40.2% were classified as blue collar or unemployed, and

19.1% were classified as homemakers. The study identified 56 households for which the deceased were accounted and income data was available. Of the 56 households, 75.0% had an annual household income of less than $35,000 (Chiu et al., 2013)

Tornado Tracks and Swaths for April 27, 2011
Northern and Central Alabama

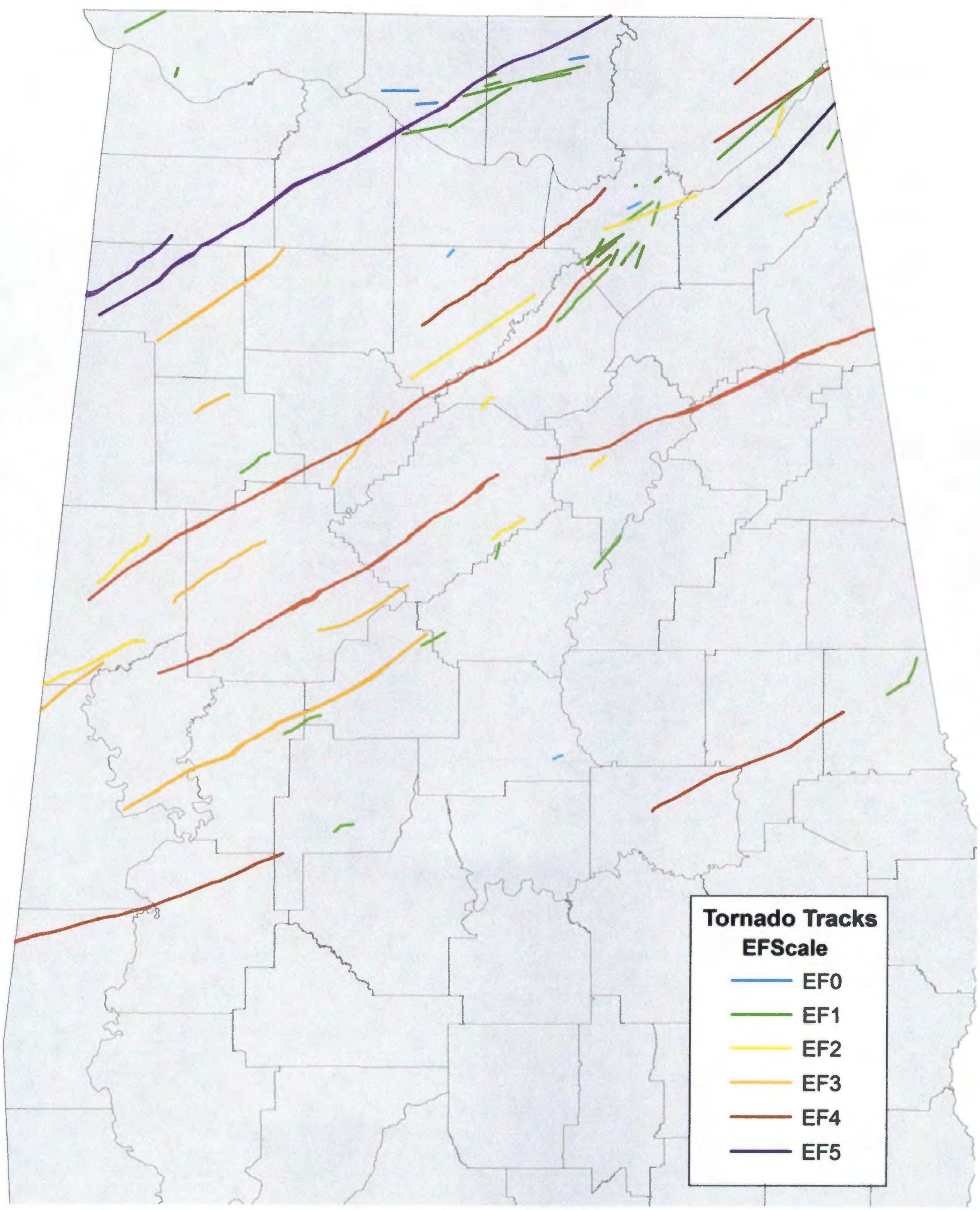

Figure 11

Community Level Analysis: Long Track, Sustained Tornadoes

Multiple medium to long track tornadoes occurred across the state of Alabama on April 27th, three of which were storms that created EF-4 damage that struck central and north central portions of the state including the cities of Tuscaloosa and Birmingham. One of these was an EF-5 intensity tornado that swept across northwest Alabama, just missing the city of Huntsville. Although these tornadoes were similar in intensity of damage, they resulted in different fatality, injury, and damage outcomes, given their exact track across the state and the census tracts affected by each. The three EF-4's were the Cordova, Tuscaloosa-Birmingham, and Shoal Creek-Ohatchee-Argo tornadoes with the EF-5 being the Hackleburg-Phill Campbell tornado. When combined, the EF-4's alone resulted in 100 fatalities (40.0% of total) and 1,635 injuries (78.0% of total). With the addition of the Hackleburg-Phil Campbell EF-5, 69.0% (171) of the total fatalities and 85.0% (1780) of the injuries directly related to the tornadoes are accounted for.

Cordova EF-4

In the early afternoon a tornado touched down in Pickens County and tracked to the northeast through 7 other counties. This storm peaked at over three quarters of a mile wide creating EF-4 intensity damage with 170 mph peak winds, destroying places such as Blountsville and Cordova. The tornado tracked for 127.8 miles over the course of 2 hours and resulted in 54 fatalities and 13 injuries (Gordon et al., 2012).

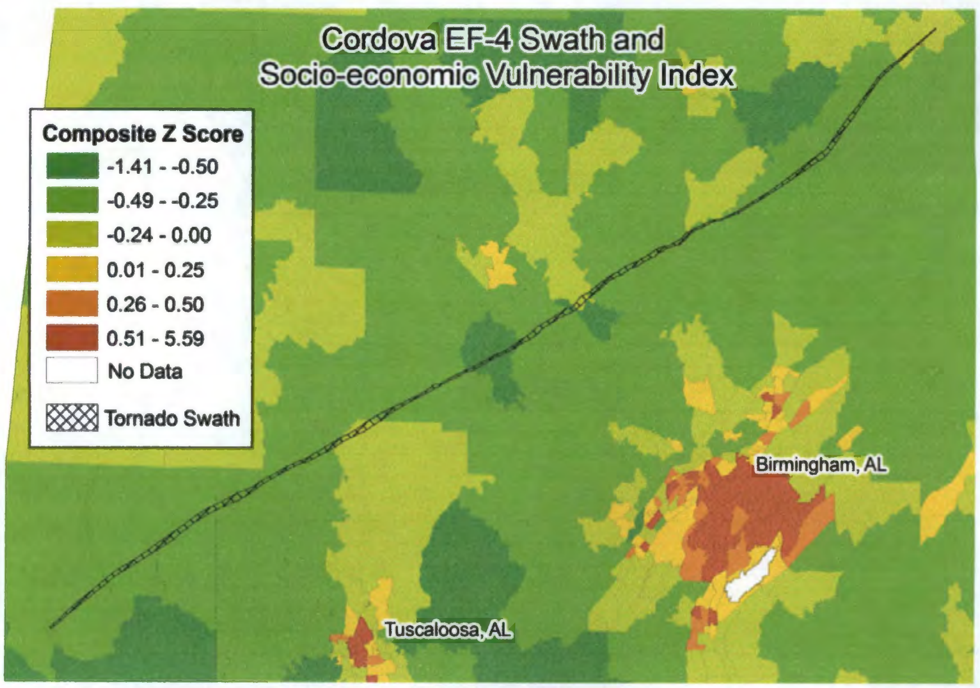

Figure 12

Tuscaloosa-Birmingham EF-4

The most destructive and deadly of all of the tornadoes that occurred on that day was the EF-4 that ravaged Tuscaloosa and northern Birmingham. The tornado initially touched down just before 5:00 PM in rural northern Greene County and then proceeded to move northeastward through 2 other counties. This tornado tracked for 80.7 miles and was a mile and a half wide at its greatest extent. It resulted in EF-4 intensity damage in and around the city of Tuscaloosa with winds topping out at 190 mph. According to the Alabama Emergency Management Agency, 12.0% of the city was destroyed with more than 7,000 people becoming unemployed as a result. Of the 65 fatalities directly related to this tornado, 66.0% of them occurred within the city of Tuscaloosa. It also resulted in 1,257 destroyed homes, 4,105 damaged homes, 114 destroyed commercial buildings, and another 242 damaged (Gordon et al., 2012). The tornado progressed northeast where it impacted the northwestern suburbs of Birmingham, resulting in additional fatalities and injuries until it finally lifted 91 minutes after touchdown northeast of downtown Birmingham. Altogether, this tornado resulted in 65 fatalities (25.5% of total) and at least 1,500 injuries.

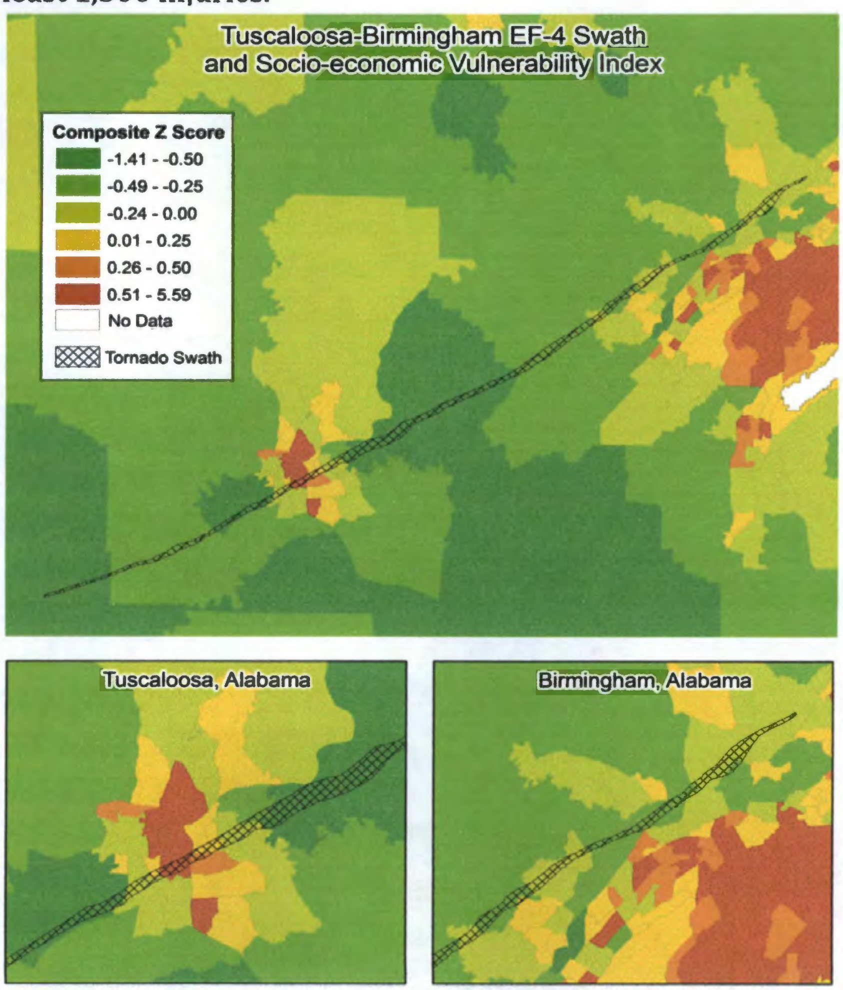

Figure 13

Shoal Creek-Ohatchee-Argo EF-4

The same supercell that produced the Tuscaloosa-Birmingham EF-4 produced yet another strong tornado just over 10 miles to the northeast of where the previous tornado had lifted. This tornado touched down along the eastern border of Jefferson County and tracked to the northeast through four other counties. The tornado tracked for 71.3 miles and produced EF-4 intensity damage with winds peaking at 180 mph, leading to 22 fatalities and 81 injuries along its path. It destroyed over 250 homes with seven of the 22 fatalities occurring in an assisted living facility housed in two mobile homes. The supercell that produced these tornadoes formed in Mississippi earlier that day and tracked all the way to North Carolina where it dissipated more than seven and a half hours later (Gordon et al., 2012).

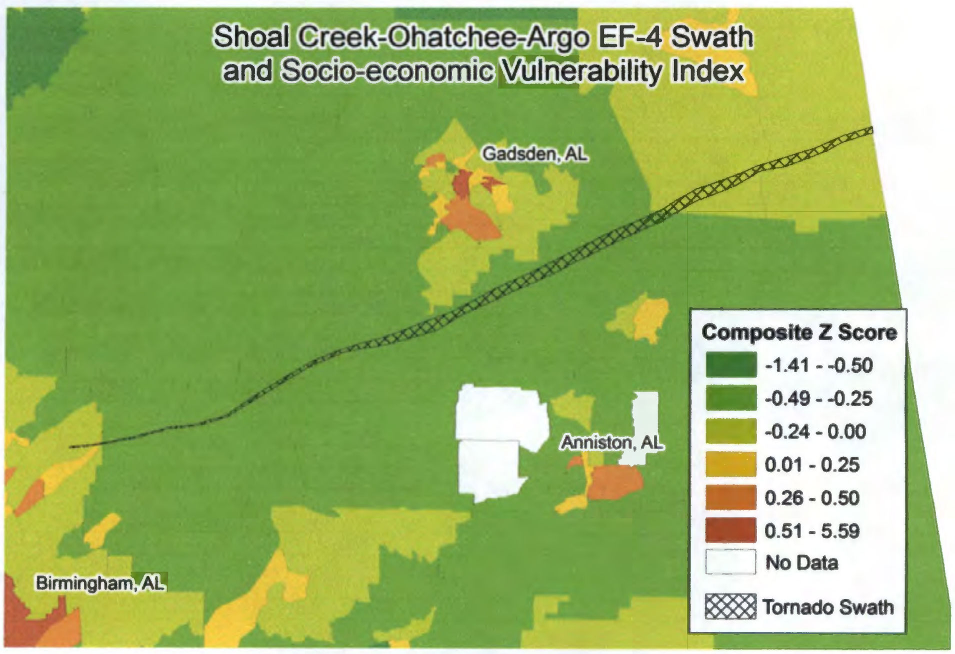

Figure 14

Hackleburg-Phil Campbell EF-5

This tornado formed and touched down just inside the Alabama-Mississippi border in southwest Marion County. It continued to strengthen as it traveled to the northeast across five additional counties. As it reached EF-5 intensity, estimated maximum winds of 210 miles per hour, it destroyed the towns of Hackleburg and Phil Campbell and continued its trek towards the northeast, where it skirted just to the north of Huntsville. By the time it passed into the state of Tennessee, it had traveled 128.8 miles across the state of Alabama and resulted in 71 fatalities and 145 injuries (Gordon et al., 2012).

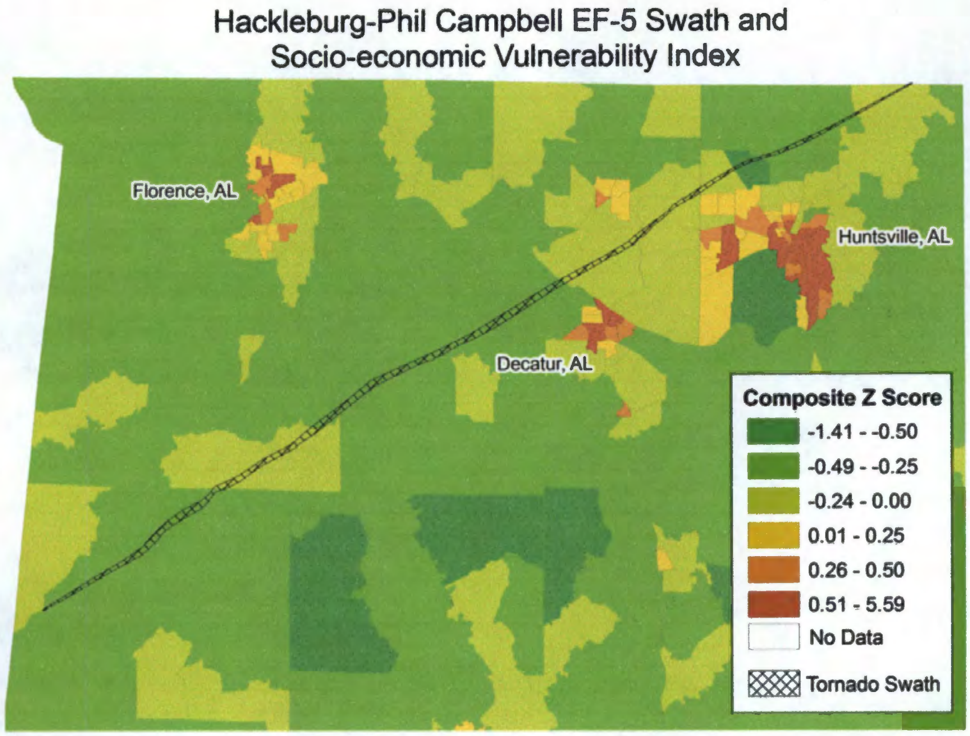

Figure 15

Table 8: Breakdown of each of the discussed tornadoes by max winds, max width, fatalities, and injuries.

Tornado	EF-Scale	Max Winds (mph)	Max Width (miles)	Fatalities	Injuries
Cordova	4	170	0.82	13	54
Shoal Creek	4	180	1.09	22	81
Tuscaloosa-Birmingham	4	190	1.62	65	1500
Hackleburg-Phil Campbell	5	210	1.36	71	145

Tornado Impact Variability

Although each of these tornadoes were similar or fairly similar in EF-scale intensity and maximum winds, we see variation in directly related fatalities and injuries from one tornado to the other. This could largely be attributed to the geographic location and socioeconomic make-up of the communities (census tracts) they impacted. As it can be seen, although the Tuscaloosa-Birmingham EF-4 tornado had slightly lower maximum wind speeds and displayed a lower grade of damage intensity as compared to the Hackleburg-Phil Campbell EF-5, the EF-4 resulted in a comparable number of fatalities and many more injuries. It can also be seen that when comparing the three deadliest EF-4 tornadoes (Cordova, Shoal Creek, Tuscaloosa), which displayed similar characteristics, the Tuscaloosa tornado resulted in a considerably higher number of injuries and fatalities as compared to the other two. This could be attributed to the fact that the Tuscaloosa tornado tracked through communities (census tracts) that, according to our socio-economic vulnerability index, were at a higher susceptibility, or vulnerability, to incurring death or injury during a severe weather event such as a tornado. This tornado tracked through census tracts that displayed, on average, a greater composite index score as compared to the three other tornadoes discussed above (Table 9).

Table 9: Each of the 4 discussed tornadoes and the average socio-economic vulnerability score of the composite as well as each individual contributing component for the census tracts impacted by each tornado respectively.

Tornado	Cordova	Shoal Creek	Tuscaloosa-Birmingham	Hackleburg-Phil Campbell
Number of Census Tracts Impacted	21	14	35	23
Mean Composite Score	-0.36	-0.30	-0.10	-0.31
Component 1 Mean	-0.69	-0.64	0.03	-0.67
Component 2 Mean	-0.47	-0.45	0.20	-0.45
Component 3 Mean	-0.31	-0.30	-0.03	-0.29
Component 4 Mean	-0.20	0.10	-0.36	0.06
Component 5 Mean	-0.13	-0.22	-0.34	-0.17

The Cordova, Shoal Creek, and Hackleburg-Phil Campbell tornadoes impacted census tracts with average vulnerability scores between -0.30 to -0.40 and the Tuscaloosa-Birmingham tornado impacted tracts that had an average vulnerability score of -0.10. As previously outlined, a higher score (i.e. more positive and/or less negative) correlates to a greater, or increased, vulnerability. This particular tornado, when compared to the other three, impacted census tracts that were at a greater vulnerability as a result of a tornadic event. This seems to correlate well with the result of this particular outbreak, given the fact that the Tuscaloosa-Birmingham tornado resulted in more injuries and fatalities combined as compared to the three other deadliest tornadoes that occurred throughout this day.

Another notable result concerns which particular components were the largest contributors to an increased vulnerability score for the census tracts affected by the aforementioned tornadoes. For the Cordova, Shoal Creek, and Hackleburg-Phil Campbell tornadoes, the two components that displayed, on average, the largest contributions to an increased vulnerability were 'Lack of Education and Access to Resources' and 'Elderly Populations and Infrastructure'. The two components that displayed the largest contributions to a decreased vulnerability for these situations were 'Population Density' and 'Wealth'. The exact opposite was the case for the Tuscaloosa-Birmingham tornado. Components 1 and 2 were the largest contributors to an increased vulnerability with components 4 and 5 being the largest contributors to a decreased vulnerability. This appears to largely be linked to the urban vs. rural nature of many of the affected census tracts.

The Cordova, Shaol Creek, and Hackleburg-Phil Campbell tornadoes tracked largely across tracts that would be considered rural, with only smaller towns being affected. The Tuscaloosa-Birmingham tornado, although it did affect some rural areas, impacted the urban centers of Tuscaloosa and the suburbs of Birmingham, where much of the damage, fatalities, and injuries accrued. The vulnerably in rural communities is predominantly linked to an overall lack of access to education and resources as well as the fact that they are often older, both in demographic make-up and infrastructure (Table 5). The urban landscape on the other hand tends to be more vulnerable because of high population and building densities as well as the predominance of lower income, higher poverty communities. Based on this information, had the Shoal Creek tornado tracked slightly farther to the north and impacted the town of Gadsden, and if the Hackleburg-Phil Campbell tornado had tracked slightly to the south and impacted Decatur and Huntsville, more fatalities, injuries, and damages would have been likely given these regions' increased vulnerability.

Community Level Analysis: Other Notable Tornadoes

Cahaba Heights EF-2

This particular tornado was one of the shortest tracks and shortest lived tornadoes that occurred during the outbreak. It touched down in suburban Birmingham and was only on the ground for 6 minutes, passing over 7.76 miles of ground. Its winds peaked at 120 miles per hour and led to damaged homes and commercial buildings along its path (Gordon et al., 2012). Although this tornado only resulted in EF-2 intensity damage and no fatalities, it did result in 61.0% of the total injuries directly related to the 9 EF-2 tornadoes that occurred across Alabama. It can be seen that this particular tornado moved across 5 census tracts that are considered highly vulnerable. The average vulnerability score for these 5 affected tracts is 0.51. Had this tornado been of a greater intensity, it is highly plausible it would have resulted in many more injuries and fatalities as well.

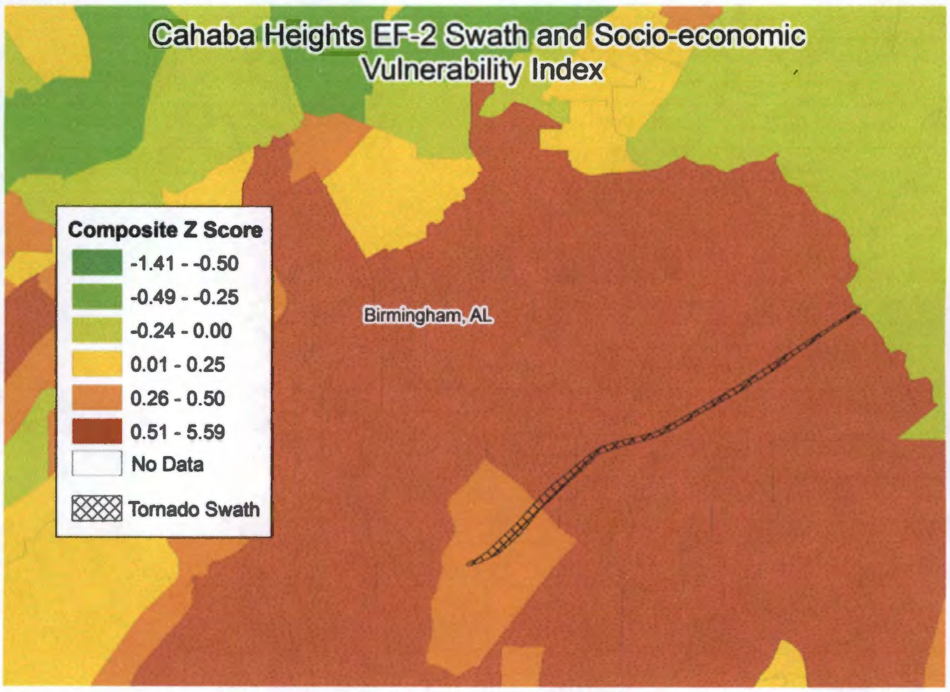

Figure 16

Sawyerville-Eoline EF-3

This tornado first touched down in a rural region of southwestern Greene County and tracked to the northeast through 2 other counties, impacting the small towns of Sawyerville and Eoline. It resulted in EF-3 intensity damage, maximum winds of 145 miles per hour, and at its greatest width was just over one mile wide. Its path was 72.13 miles long and resulted in 7 fatalities and 50 injuries. Based on these values, this EF-3 was arguably one of the more intense EF-3's that occurred throughout the day. From these numbers, it would have been expected that the track of this tornado had impacted census tracts that were indicated as being moderately or highly vulnerable. However, in this particular case, we do not see this occurring. This tornado tracked largely through communities that, according to the vulnerability index, did not appear to be at a high risk of suffering from fatalities or injuries during a tornadic event. The overall average composite vulnerability score for the 9 affected census tracts was -0.61, a value that indicates fairly low vulnerability. Although the index did not correlate positively to this circumstance, it is understood that not all events will affect areas accordingly, and other underlying, unpredictable, or unknown circumstances could produce such a correlation.

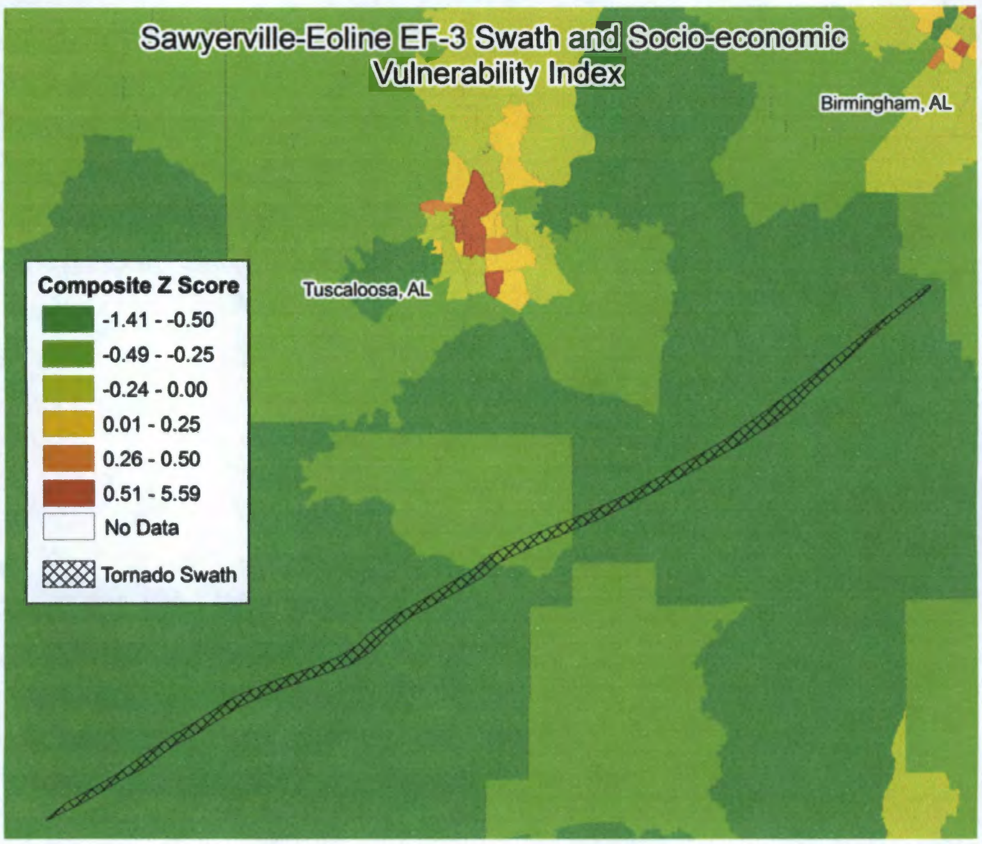

Figure 17

Conclusion and Future Direction

Although no consensus exists among governmental agencies, scholars, or the general public as to what key components increase the level of susceptibility within a community, they can all agree that studies focused on this analysis are key to developing resilient communities of the future (Cutter et al., 2003). Socio-economic vulnerability is the product of a culmination of many different dimensions and factors as a result of the differing physical environments and demographic characteristics displayed among varying communities. These factors vary over both time and geographic space, making socio-economic vulnerably a dynamic and ever-changing component of local communities. By being able to better understand what factors influence (increase or decrease) vulnerability, local and national governments can better identify those communities that are more than likely at a greater risk in order to ultimately increase their resilience in preparation for possible future events.

A multitude of factors were analyzed and selected for this study and were supported in literature as notable influences on local community susceptibility to severe weather. Based on the case study analysis of the 2011 Alabama tornado outbreak, the index generated appears to work well for comparative analysis, with a focus on severe weather applications. For most cases, those tornadoes that tracked through census tracts with higher vulnerability scores, tended to show increased fatalities, injuries, and monetary damage. This showed that the factors included in the index are viable and measurable aspects of communities that lead to increased susceptibility to severe weather. Given that this index was generated via the use of U.S. Census Bureau datasets and at the census tract level, the methods and approaches of this study can be replicated for other areas of study within the United States and for other given time periods for which data are available.

In general, the composite index correlated highly vulnerable areas to increases in fatalities, injuries, and damage, but we understand that it did not replicate this correlation for every event. That being said, the index itself is not foolproof and could be enhanced in order to better capture community level vulnerabilities that may have been missed or not included in this study. Furthermore, this index was also used specifically to analyze tornadic events on local communities, but could be applied to other weather hazards to analyze it effectiveness in identifying areas that are vulnerable to all environmental hazards. Our hope is that this index and the subsequent information and analysis can provide governments, decision makers, and citizens with the tools necessary to better understand socio-economic vulnerability within local communities. Through future assessments of community level vulnerability, studies similar to this one can help lead to policy changes or improvements to ensure increased safety for susceptible populations. The ultimate goal is that this information is used or elaborated upon to identify those areas at a greater probability of suffering losses during a severe weather event in order to prepare, protect, and educate those local citizens that are at greatest risk.

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